치의학박사 학위논문

Evaluation of the radiopacity of contemporary resin cements using photostimulable phosphor plates

영상판을 이용한 레진시멘트의 방사선불투과성 평가

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서울대학교 대학원

치의과학과 영상치의학 전공

안 서 영

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이 논문을 치의학박사학위논문으로 제출함

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치의과학과 영상치의학 전공

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안서영의 치의학박사 학위논문을 인준함

2019년 7월

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Abstract

Evaluation of radiopacity of contemporary resin cements using photostimulable phosphor plates

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Objective: Luting materials fill the minute voids between an indirect restoration and tooth or implant abutment and the use of resin-based luting cements in dentistry has increased considerably. Resin cements may have lower radiopacity compared with conventional cements, however, there is limited information available regarding this. Radiopacity is a prerequisite for dental materials such as cements and resin in order to provide a suitable contrast between the tooth and dental materials.

The aims of the current study were to examine the effects of exposure settings on the evaluation of radiopacity and to examine the radiopacity of 14 contemporary resin cements using photostimulable phosphor plates (PSPs) using optimum exposure setting.

Materials and Methods: Disc specimens (N=84, n=6 per group, ϕ7 mm×1 mm) were prepared using 14 resin cements (BisCem, Clearfil SA LUTING, Duolink, Maxcem Elite, M−bond, Multilink N, Nexus 3, Panavia F2.0, Rely X U200, Secure, SmartCem2, U−Cem, Variolink, and Zirconite).

First, 4 of the 14 resin cements (Duolink, Multilink N, Panavia F2.0, and U−Cem) were selected to evaluate the effects of exposure settings and to determine the optimum exposure setting. Nine different exposure settings were used in various combinations of the tube voltage (kVp), tube−receptor distance (cm), and exposure time, including, 60 kVp, 30 cm, 0.100/0.125/0.160/0.200 seconds; 70 kVp, 30 cm, 0.100/0.125/0.160 seconds; and 60 kVp, 40 cm, 0.160/0.200 seconds. The tube current was 7 mA in all the setting combinations. Each cement along with an aluminum step wedge and a tooth specimen were radiographed with the PSP.

To analyze the radiopacity of the 10 remaining resin cements, disc specimens (BisCem, Clearfil SA LUTING, Maxcem Elite, M−bond, Nexus 3, Rely X U200, Secure, SmartCem2, Variolink and Zirconite) were radiographed with an aluminum step wedge

and a tooth specimen using PSP with 'exposure setting 8' of 60 kVp, 40 cm, and 7 mA, at an exposure time of 0.16 second, which showed the best accuracy.

The gray value of the resin cements, aluminum step wedge, and the tooth was measured using the NIH ImageJ software (available at http://rsb.info.nih.gov/ij/) and subsequently, the gray value was converted into absorbance. A linear regression model was plotted as a function between the absorbance and the aluminum thickness and the radiopacity of the resin cements was calculated in aluminum-equivalent millimeters (mm Al) based on the equation. The coefficient of determination R^2 was evaluated to find the best exposure setting, and the Kruskal-Wallis and Tukey HSD tests were used to compare the radiopacity of the resin cements depending on the 9 different exposure settings.

Results: The corresponding R^2 values of the absorbance of the aluminum step with PSP showed high linearity between 0.9983 and 0.9997 using the 9 different exposure settings and the 'exposure setting 8' revealed the highest accuracy. The radiopacity of the 4 resin cements with different shades and the tooth structure, except Panavia F2.0 did not vary according to the 9 different exposure settings as follows: Duolink (1.02±0.13~1.31±0.23), Multilink N (4.23±0.23~4.36±0.29), U-Cem (1.90±0.46~2.05±0.25), Panavia F2.0 (1.21±0.22~1.40±0.24), dentin (0.70±0.21~1.00±0.21), and enamel (1.68±0.22~1.84±0.21).

The radiopacity of the remaining 10 resin cements at 'exposure setting 8' showed that Variolink (5.71±0.09) had the highest radiopacity followed by Nexus 3 (4.68±0.14), SmartCem2 (3.69±0.14), Maxcem Elite (2.95±0.12), Secure (2.91±0.11), and Rely X U200 (1.96±0.19). The radiopacity of Clearfil SA LUTING (1.71±0.10), Zirconite (1.60±0.08), and BisCem (1.58±0.13) were between those of enamel (1.81±0.20) and dentin (0.67±0.12). The radiopacity of M-bond (0.31±0.45) was lower than that of dentin or aluminum of the same thickness.

Conclusion: The aluminum step shows high linearity of absorbance using PSP regardless of the exposure settings and the radiopacity of the resin cements is not different under the various exposure settings using PSP. The radiopacity of the 14 tested contemporary resin cements, except M-bond, is greater than those of aluminum or dentin of the same thickness, thus complying with the requirements of the International Organization for Standardization.

Keyword : Radiopacity; Resin Cements; Photostimulable Phosphor Plates; Digital Radiography; Aluminum Step Wedge

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Contents

I. Introduction

Luting materials fill the minute voids between an indirect restoration and tooth or implant abutment and mechanically lock the restoration in place to prevent its dislodgement during function.[1] They are applied to veneers, crowns, inlays or onlays, posts, and implant–prosthesis.[2] The use of resin–based luting cements in dentistry has increased considerably because they have numerous advantages over conventional cements such as high esthetics, viscosity, and strength and low microleakage.[2–4] However, the radiopacity of these resin–based luting cements may be a disadvantage due to the low filler content compared to conventional cements, especially in terms of esthetics, and it is thus necessary to further evaluate their radiopacity.

Radiopacity is a prerequisite for dental materials such as cements and restorations because it allows for a suitable contrast between the tooth structures and the dental materials.[5–7] Wilson[8] reported that a majority (81%) of the peri–implant diseases were induced by excess dental cements. Sufficient radiopacity of the dental material facilitates accurate diagnosis of not only the excess cements but also many conditions including secondary caries, interfacial gaps, faulty proximal contours, and voids in the material.[5,8–11]

Therefore, the dental materials need to have enough radiopacity to be distinguished from the tooth background.[12] The International

Organization for Standardization (ISO)[6] and the American National Standards Institute/American Dental Association[13] have established the quantitative standards for the radiopacity of several dental materials using an aluminum step wedge with purity of at least 98% by mass fraction as reference. The radiopacity of resin−based luting cements should be equal to or greater than that of aluminum of the same thickness.[6] The radiopacity of dentin is approximately equivalent to that of aluminum of the same thickness, and the radiopacity of enamel is approximately twice that of aluminum of the same thickness.[14]

In conventional radiography, X−ray films, densitometers, and spectrometers[7,15,16] are commonly used for the examination of radiopacity. Digital intraoral radiography was introduced in 1989 and several types of sensors have been developed; charge−coupled devices (CCDs), complementary metal oxide semiconductors (CMOSs), and photostimulable phosphor plates (PSPs).[17] In digital radiography, the gray value has an inverse relationship with the optical density, with black being assigned a value of 0 and white a value of 255 (for an 8−bit system). Digital radiographic systems have numerous advantages over conventional radiography, such as easy and precise measurements, reduction of radiation doses, and more consistent results.[11,12,18] This is because they are more sensitive compared to conventional films[18] and they don' t undergo the process of development and fixation, which can result in significant variations.[11]

Many studies have evaluated the radiopacity of dental materials using various receptor, including film, digitized image, CCDs, CMOSs and PSPs and most of them have used a single receptor or a combination of two receptors for evaluation.[16,19,20] Recently, PSP was recommended for the radiopacity evaluation among various methods due to its accuracy and convenience.[20] Some studies have examined the effects of exposure settings on the evaluation of radiopacity using direct digital radiography such as CCDs or CMOSs and have reported different values of radiopacity according to the exposure settings.[2,21,22] However, the effects of exposure settings on radiopacity evaluation using PSPs have been rarely studied. Since the use of resin-based luting materials for restorations or implant-prosthesis has increased, it is important to evaluate the value of radiopacity of contemporary resin cements.

The aims of this *in vitro* study were to examine the effects of exposure settings on the evaluation of the radiopacity of resin cements and to evaluate the radiopacity of 14 contemporary resin cements using PSPs with optimum exposure setting.

II. Materials and Methods

1. Specimen preparation

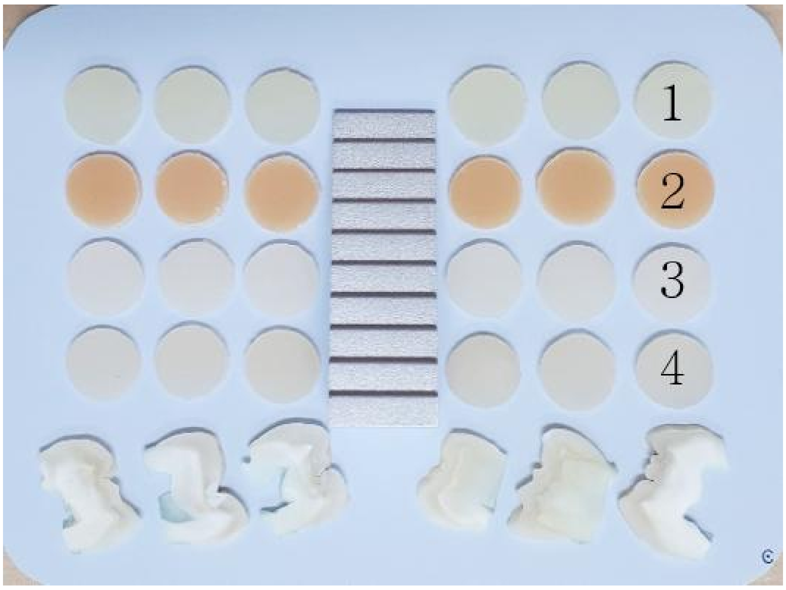
Fourteen resin cements were evaluated in this study (Table 1). The materials were treated according to manufacturers' instructions, and the experiments were carried out at room temperature. The cements were mixed, inserted into the mold between 2 glass slides, and a curing light source (Elipar TriLight; 3MESPE, Seefeld, Germany; standard mode) was applied to the cements with an output intensity of 750 mW/cm^2 monitored by a built-in radiometer. Six specimens measuring 7 mm diameter by 1 mm thickness, were made for each tested material resulting in 84 specimens in total (Figure 1). The thickness of each specimen was verified with a digital micrometer (293-821LCD Digimatic Micrometer; Mitutoyo, Kawasaki, Japan) at three locations with a critical tolerance of 1.00±0.01 mm. According to ISO 4049[6], the diameter of the finished specimen must be more than 14.8 mm for testing the general characteristics such as film thickness, flexural strength, and radiopacity and ISO 13116[23] suggests that a diameter of 10 mm is suitable for disc-shaped specimens of all dental materials. In previous studies,[2,7,22,24-26] disc specimens of luting cements with diameters between 4.1 mm and 10 mm (mean, 6.4±2.2 mm) were used for testing the radiopacity. However, the specimen thickness is more important than the diameter for the radiopacity test. Thus, considering the size of the area for image analysis and the convenience of fabrication, a diameter of 7 mm was chosen.

Six 1-mm-thick tooth specimens were prepared from premolars and molars in the longitudinal direction without the root portion using a low-speed diamond saw (Isomet, Buehler, IL, USA). A free-standing aluminum step wedge was fabricated with a size of 30 mm x 10 mm x 10 mm from a 99.5% pure aluminum block (Alu-Keil; PEHA Medikal Ger□te GmbH, Sulzbach, Germany) and the thickness of each step was verified within ±0.01 mm using a Vernier caliper (Whitworth Electronic Digital Caliper Metr. ISO 6 Inches 150 Millimeters CRP).

Table 1. Resin cements investigated in this study

Product (Shade)	Manufacturer	Lot number
BisCem (Translucent)	Bisco, Schamburg, USA	1300004788
Clearfil SA LUTING (Universal)	Kuraray, Tokyo, Japan	0375AB
Duolink (Translucent)	Bisco, Schamburg, USA	1300004782
Maxcem Elite (Clear)	KERR, Orange, USA	4678975
M-bond (Clear)	Tokuyama, Tokyo, Japan	067E73
Multilink N (Transparent)	Ivoclar Vivadent, NY, USA	S34718
Nexus 3 (Clear)	KERR, Orange, USA	4870783
Panavia F2.0 (Light)	Kuraray, Tokyo, Japan	051402
Rely X U200 (A2)	3M ESPE, St. Paul, USA	511446
Secure (Translucent)	SunMedical, Moriyama, Japan	GF1
SmartCem2 (Translucent)	Dentsply, York, USA	1206271
U-Cem (Universal)	VERICOM, An-Yang, Korea	UC3431UA
Variolink N (Transparent)	Ivoclar Vivadent, NY, USA	V16166
Zirconite (Translucent)	BJM LAB, Or-yehuda, Israel	4197HQBSE ARCTRZKR

Figure 1. Examples of specimens on the PSP (1. Duolink, 2. Panavia F2.0, 3. U-cem, 4. Multilink N)



PSP, photostimulable phosphor plate

2. Image acquisition

2. 1. Evaluation of various exposure settings

A special holder (Figure 2) was designed and fabricated to ensure constant exposure settings by maintaining the location of the detector and the X-ray machine and to place the specimens near the center of the PSPs. The PSP was positioned on a 1 mm sheet of lead.

Nine different exposure settings were used in various combinations of the tube voltage (kVp), tube-receptor distance (cm), and exposure time, including, 60 kVp, 30 cm, 0.100/0.125/0.160/0.200 seconds; 70 kVp, 30 cm, 0.100/0.125/0.160 seconds; and 60 kVp, 40 cm, 0.160/0.200 seconds (Table 2). The tube current was set at 7 mA for all combinations. According to ISO 4049[6] and ISO 13116[23], dental X-ray units are capable of operating at 65±5 kV[6] and a cathode target-film distance of 300 mm to 400 mm.[6,23] Therefore, a tube voltage of 60 kVp and 70 kVp and tube-receptor distance of 30 cm to 40 cm were used in this study. ISO 4049[6] and ISO 13116[23] did not recommend a specific exposure time or tube current but required repetition of the procedure to find an appropriate exposure time. Therefore, this study was designed with clinical exposure times of 0.100/0.125/0.160/0.200s and 7 mA tube current, since this was the only current setting available with the dental X-ray machine.

Four of the 14 resin cements, including Duolink (translucent), Multilink N (transparent), Panavia F2.0 (light), and U-Cem (universal) were selected through literature review[16,20,22,25] to examine the effects of various exposure settings because these resin cements not only had diverse mm Als randing from low to high values but also had different shades. Each specimen along with the aluminum step wedge and a tooth specimen were radiographed with the PSP (CS 7600 image plate No. 4; Carestream Health, Inc., Rochester, NY, USA) using a dental X-ray machine (CS 2200 Intraoral X-ray System; Carestream Health, Inc., Rochester, NY, USA) under 9 the exposure settings. The CS 7600 system saves the image in three different types and the raw unprocessed digital images, named as 'U image', were saved in 8-bit TIFF format for the subsequent measurement of gray value (Figure 3).

2. 2. Evaluation of the radiopacity of contemporary resin cements

After evaluation of the exposure setting, the images of the 10 remaining contemporary resin cements (BisCem, Clearfil SA LUTING, Maxcem Elite, M-bond, Nexus 3, Rely X U200, Secure, SmartCem2, Variolink and Zirconite), aluminum step wedge, and the teeth were taken under 'exposure setting 8' showing the highest accuracy, that is, 60 kVp, 40 cm, 0.16 second, and 7 mA. The unprocessed 'U image' was saved in 8-bit TIFF format for the subsequent measurement of gray value (Figure 4).

Figure 2. A special holder design for standardization (A) and the experimental setup (B)

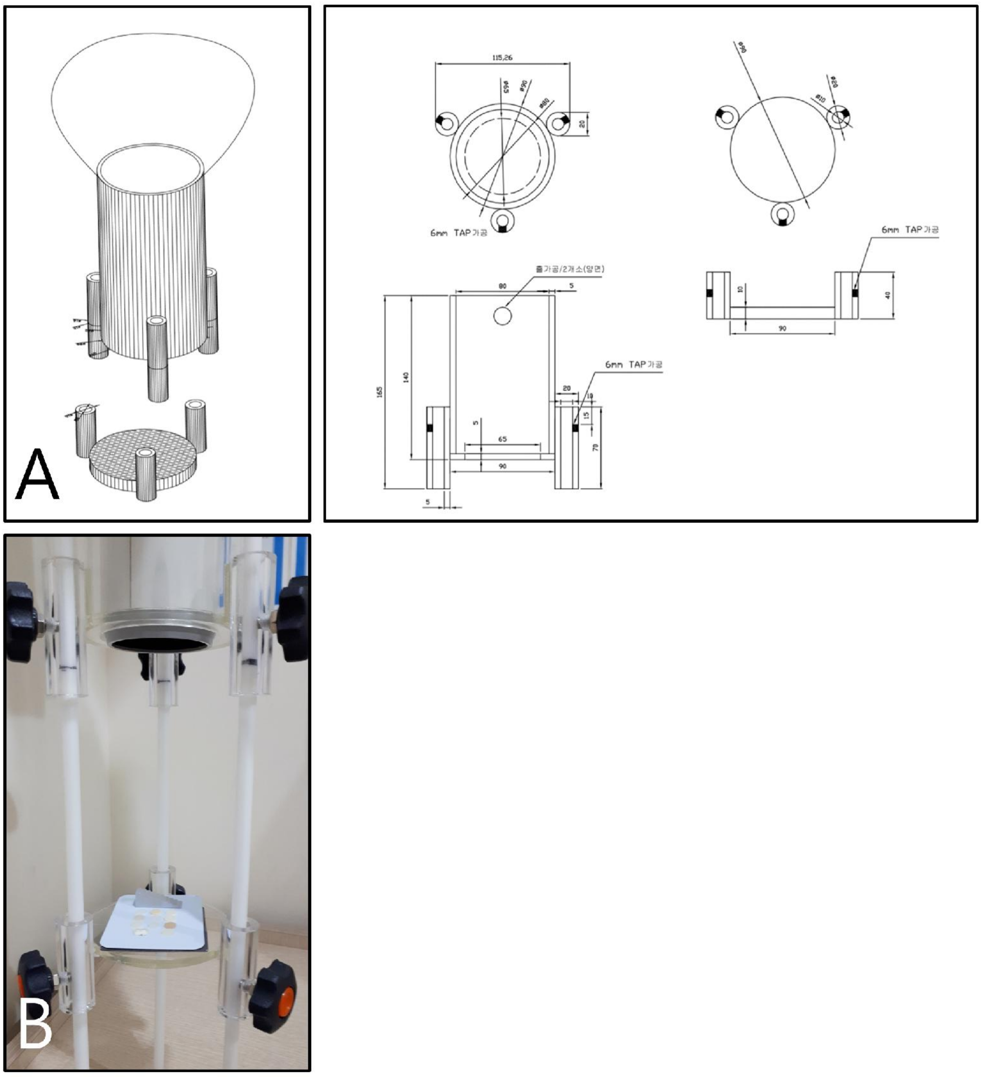
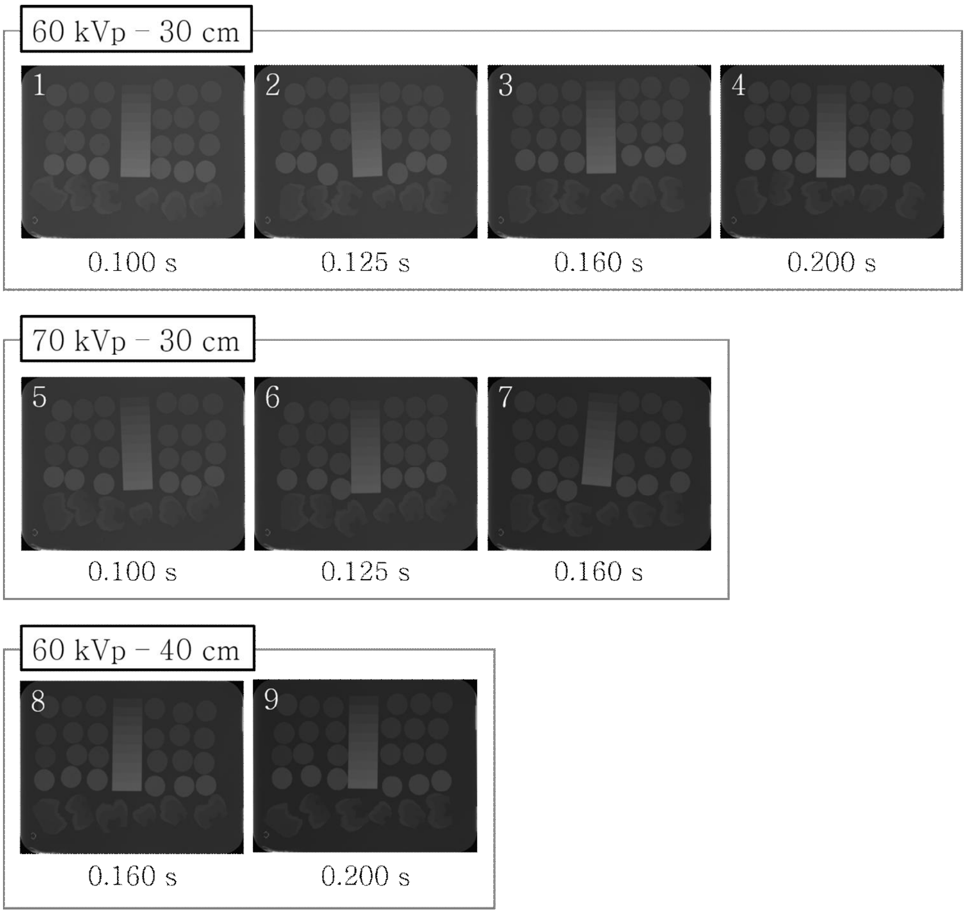
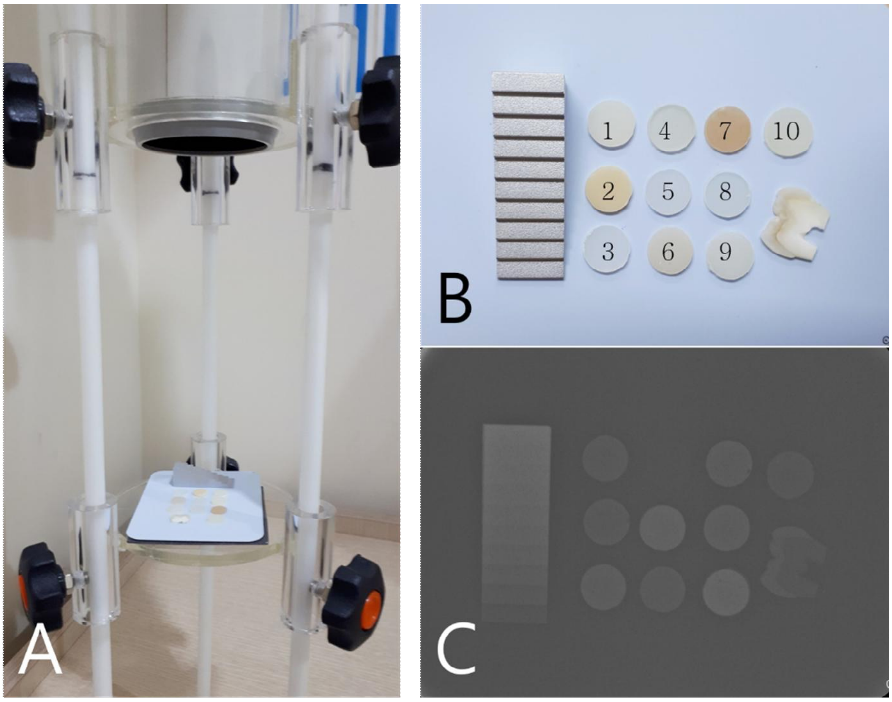


Figure 3. Radiographic images containing tooth structure, aluminum step wedge and the tested 4 resin cements obtained from the PSP under various exposure settings



PSP, photostimulable phosphor plate
; kVp, Tube voltage; cm, Tube−receptor distance; s, second

Figure 4. Radiopacity evaluation of 10 contemporary resin cements. Experimental setup (A), specimens on the PSP (1. BisCem, 2. Clearfil SA LUTING, 3. Maxcem Elite, 4. M-bond, 5. Nexus 3, 6. Rely X U200, 7. Secure, 8. SmartCem2, 9. Variolink N, 10. Zirconite) (B) and radiographic image (C)

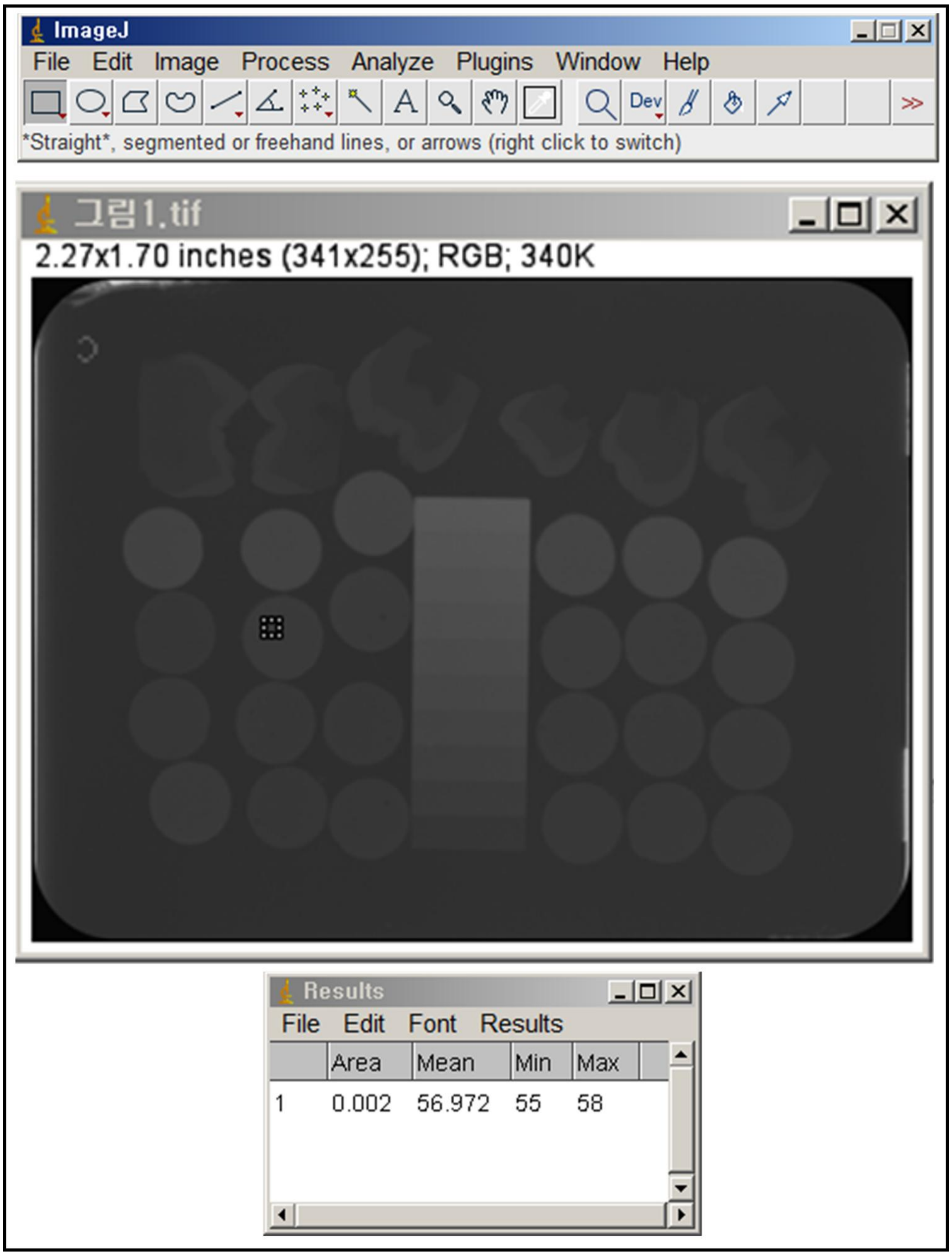


PSP, photostimulable phosphor plate

3. Image analysis

The images were analyzed using NIH ImageJ software (available at http://rsb.info.nih.gov/ij/) to measure the gray value using the measuring tool. According to ISO 4049[6], five rectangular areas of interest (10×10 pixels in size) were selected within homogeneous areas without a void and the average gray values were measured for the resin cements, enamel, and dentin, as well as for each of the 10 steps of the aluminum step wedge (Figure 5). Subsequently, the gray value was converted into absorbance using the following equation: $A = -\log(T) = -\log(1 - G/255)$, where A is the absorbance, T is the transmission, and G is the gray value (0 to 255).[27] A linear regression model was plotted as a function between the absorbance and the aluminum thickness under the 9 different exposure settings. The model equation is expressed as "$Y = a \times X + b$" and the corresponding R^2 value using Excel 2013 (Microsoft, Redmond, WA, USA). The radiopacity of the resin cements was calculated as aluminum −equivalent millimeters (mm Al)[6] based on the equation.

Figure 5. Measurement of mean gray values using ImageJ software



4. Statistical analysis

Statistical analysis was performed using SPSS for Windows version 18.0 (SPSS Inc., Chicago, IL, USA). The radiopacity of the resin cements, dentin, and enamel was expressed as the mean ± standard deviation of mm Al. The Kruskal-Wallis and Tukey HSD test were used to compare the radiopacity of the resin cements depending on the 9 different exposure settings. P-values < .05 were considered statistically significant.

III. Results

Table 2 presents 9 different exposure settings depending on the tube voltage, tube−receptor distance, and exposure time at 7 mA and the linear regression model equation with corresponding R^2 values using PSP. Figure 6 presents the incremental steps of the linear regression models of the aluminum step wedge thickness as a function of the relevant absorbencies. The model equations differed according to the exposure settings. The 60 kVp group had higher regression coefficients than the 70 kVp group. The regression coefficients for 60 kVp−30 cm−0.100/0.125/0.160/0.200 seconds settings were 0.1122, 0.1125, 0.1114, and 0.1104, respectively, and the values for 60 kVp−40 cm−0.160/0.200 seconds settings were 0.1084, and 0.1081, respectively. Whereas the regression coefficients for 70 kVp−30 cm−0.100/0.125/0.160 seconds were 0.0987, 0.0984, and 0.0917, respectively. Regarding the coefficient of determination R^2, the values of the absorbance of the aluminum step with PSP were between 0.9983 and 0.9997 and 60 kVp−40 cm−0.16 second showed the highest value with R^2=0.9997. The radiopacity of the resin cements and the tooth structure did not vary according to the 9 different exposure settings showing Duolink (1.02±0.13~1.31±0.23), Multilink N (4.23±0.23~4.36±0.29), U−Cem (1.90±0.46~2.05±0.25), dentin (0.70±0.21~1.00±0.21) and enamel (1.68±0.22~1.84±0.21), except Panavia F2.0 (1.21±0.22~1.40±0.24) (Table 3, Figure 7) and all of them were greater than the radiopacity of dentin.

Table 4 lists the radiopacity of 10 contemporary resin cements obtained using PSP and it ranged from 0.31 to 5.71 mm Al. Variolink (5.71±0.09) showed the highest radiopacity, followed by Nexus 3 (4.68±0.14), SmartCem2 (3.69±0.14), Maxcem Elite (2.95±0.12), Secure (2.78±0.23), and Rely X U200 (1.96±0.19). The radiopacity of Clearfil SA LUTING (1.71±0.10), Zirconite (1.60±0.08), and BisCem (1.58±0.13) were between enamel (1.81±0.20) and dentin (0.67±0.12). The radiopacity of M-bond (0.31±0.45) was lower than that of dentin or aluminum of the same thickness. Figure 8 shows the radiopacity of all 14 contemporary resin cements at 'exposure setting 8'.

Table 2. Exposure settings depending on the tube voltage (kVp), tube−receptor distance (Cm), and exposure time (Second) and the model equations with corresponding R^2 values (Tube current, 7 mA)

Setting	kVp−Cm−Second	Model equation	R^2
1	60−30−0.100	y=0.1122x+0.3458	0.9984
2	60−30−0.125	y=0.1125x+0.3065	0.9989
3	60−30−0.160	y=0.1114x+0.2776	0.9988
4	60−30−0.200	y=0.1104x+0.2692	0.9991
5	70−30−0.100	y=0.0987x+0.3054	0.9983
6	70−30−0.125	y=0.0984x+0.3067	0.9986
7	70−30−0.160	y=0.0917x+0.2089	0.9991
8	60−40−0.160	y=0.1084x+0.2125	0.9997
9	60−40−0.200	y=0.1081x+0.2274	0.9993

kVp−Cm−Second, Tube voltage (kVp), Tube−receptor distance (Cm) and Exposure time (Second); R^2 , Coefficient of determination

Figure 6. Linear models for an aluminum step wedge with the corresponding R^2 values obtained from various exposure settings

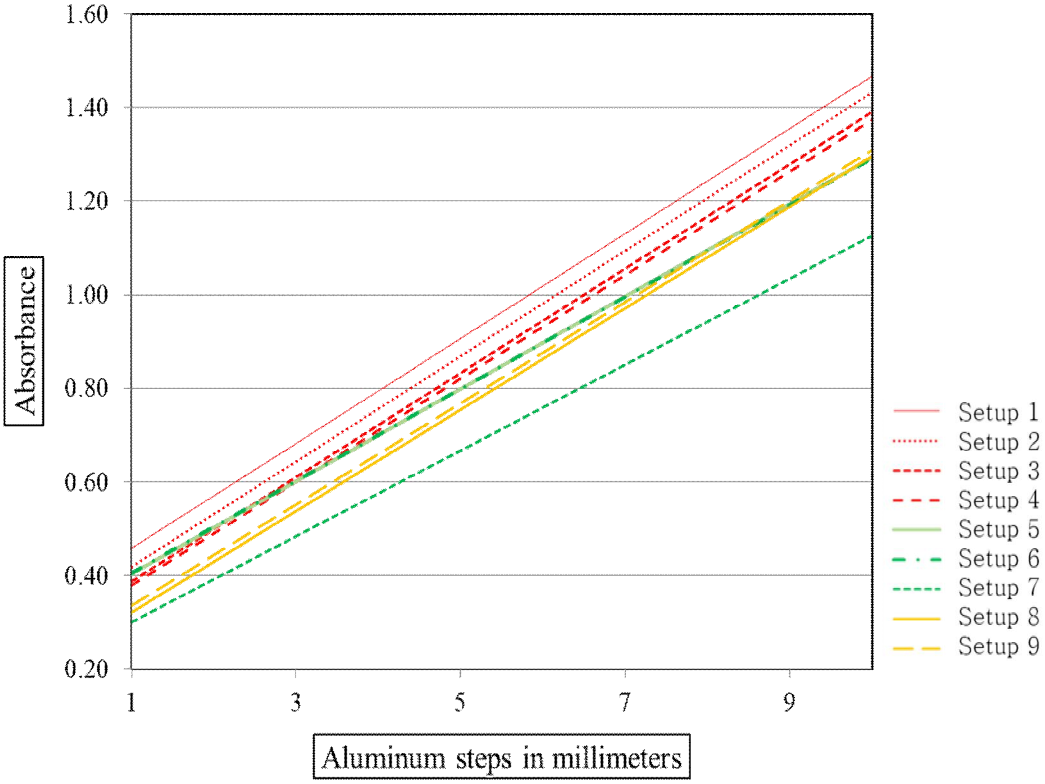


Table 3. The equivalent aluminum thickness of the resin cements, enamel, and dentin in millimeters measured using PSP under various exposure settings

Setting	Duolink	Multilink N	Panavia F2.0	U-Cem	Dentin	Enamel
1	1.02±0.13	4.25±0.28	1.21±0.22[a]	1.91±0.22	0.70±0.21	1.68±0.22
2	1.08±0.16	4.30±0.27	1.29±0.22[a,b,c]	1.97±0.22	0.84±0.16	1.84±0.21
3	1.11±0.18	4.23±0.23	1.26±0.20[a]	1.92±0.21	0.85±0.19	1.75±0.19
4	1.11±0.17	4.25±0.23	1.28±0.21[a,c]	1.96±0.23	0.89±0.20	1.80±0.26
5	1.19±0.19	4.36±0.29	1.40±0.24[c]	2.05±0.25	0.91±0.21	1.81±0.26
6	1.18±0.19	4.34±0.30	1.39±0.25[b,c]	2.04±0.25	0.88±0.22	1.83±0.26
7	1.31±0.23	4.31±0.29	1.39±0.24[c]	1.90±0.46	1.00±0.21	1.79±0.23
8	1.21±0.16	4.30±0.26	1.40±0.19[b,c]	2.00±0.24	0.98±0.17	1.82±0.21
9	1.13±0.19	4.23±0.32	1.33±0.24[b,c]	1.95±0.25	0.93±0.19	1.78±0.23

Superscript letters indicate significant differences.

Figure 7. The equivalent aluminum thickness of the resin cements, enamel, and dentin in millimeters measured under 9 different exposure settings

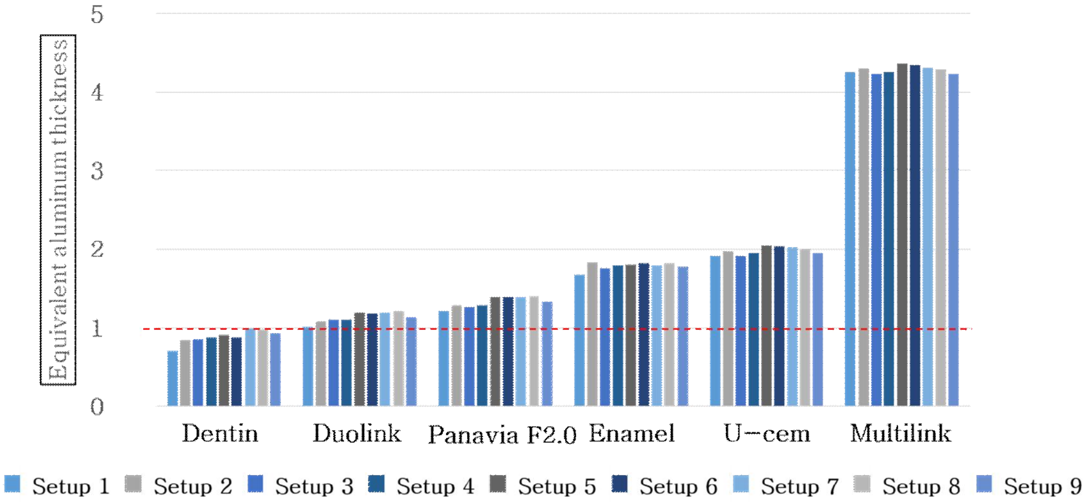
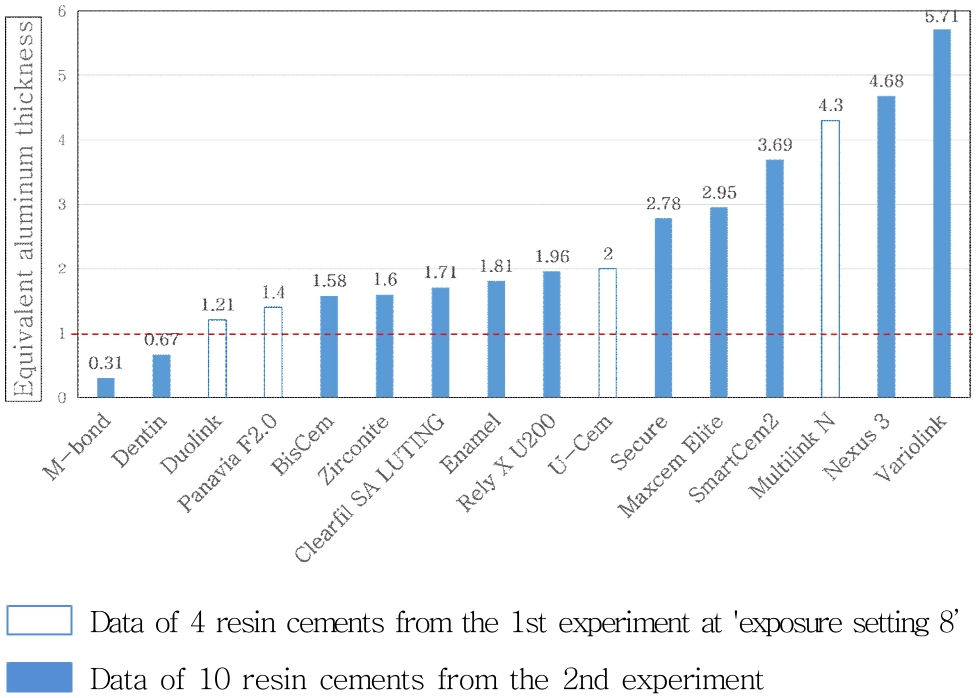


Table 4. The equivalent aluminum thickness of the resin cements, enamel, and dentin in millimeters

Resin cement	Equivalent aluminum thickness
BisCem	1.58±0.13
Clearfil SA LUTING	1.71±0.10
Maxcem Elite	2.95±0.12
M-bond	0.31±0.45
Nexus 3	4.68±0.14
Rely X U200	1.96±0.19
Secure	2.78±0.23
SmartCem2	3.69±0.14
Variolink	5.71±0.09
Zirconite	1.60±0.08
Dentin	0.67±0.12
Enamel	1.81±0.20

Figure 8. The radiopacity of 14 resin cements, enamel, and dentin in mm Al at 'exposure setting 8' (The data of Duolink, Panavia F2.0, U-Cem, and Multilink N are from the first experiment at 'exposure setting 8'.)



IV. Discussions

In this *in vitro* study, the radiopacity of resin cements under various exposure settings was examined and an optimum exposure setting was used to evaluate the radiopacity of 14 contemporary resin cements with PSP.

Many previous studies have examined the effects of the exposure parameters such as the exposure time,[2,21,22,28] tube voltage[2,29] and tube−receptor distance[21,27,30] using a digital system. In the present study, the radiopacity of the resin cements and tooth structure did not vary according to the 9 different exposure settings using PSP. Some authors[21,27−29] have reported that varying the exposure settings, such as the tube voltage,[29] exposure time and tube−receptor distance,[21,27,28] had no significant effect on the radiopacity evaluation. Rasimick et al.[21] used 2 different regression equations for precise regression, and Sabbagh et al.[28] and Wadhwni et al.[29] used only 2 different exposure settings that were not sufficient to evaluate the effects of exposure settings. An et al.[22] and Dukic[2] compared the radiopacities under several exposure settings and concluded that they differed significantly from each other under the exposure settings using CMOS (Kodak RVG 6100; Carestream Health, Inc., Rochester, NY, USA) or CCD (ProSensor; Planmeca Oy, Helsinki, Finland) sensor. Poorsattar et al.[30] also supported that various exposure settings might influence the radiopacity of dental materials on digital radiographs using PSP (Soredex, Tuusula, Finland). In this study, PSP showed high accuracy and the radiopacity of the resin cements did not differ significantly under any of the 9 exposure settings. Therefore, if the exposure setting is appropriate, a single exposure setting is sufficient for radiopacity evaluation with PSP. The differences in the radiopacity under various exposure settings may be related to the pre-image processing by the analog-digital converter and in the present study the unprocessed 'U image' was used for the measurement of the gray values instead of the processed 'P image'. An et al.[20] reported that PSP was the most precise for the radiopacity evaluation of the dental materials. In this study, the gradient of figure 9 is greater at 60 kVp than 70 kVp, which is consistent with the fact that a lower kVp results in greater image contrast.

In clinical situations, CMOS or CCD sensor are used more frequently than PSP and they provide post-processed images for the diagnosis. The final diagnostic images of PSP are also post-processed, which results in a reduction of the contrast between the dental materials or the surrounding tooth structure and the dental material. In some cases, the ranking of the similarities in the radiopacity of several materials was not consistent according to the exposure settings.[2,20] The results imply that materials with a similar radiopacity as dentin can show different radiopacity test outcomes depending on the exposure setting. Therefore, the radiopacity values should be high enough to avoid misinterpretations due to the similarity of radiopacity between the material and dentin. In the present study, the radiopacity of 4 resin cements was consistent under 9 different exposure settings with PSP, despite the proximity of radiopacity between dentin and Duolink or between enamel and U−Cem.

Numerous resin cements have been introduced in the market and radiopacities of the resin cements were tested in many previous studies with film,[7,15,16,20,25] digitized image,[16,20] direct digital image,[2,20−22,31,32] and indirect digital image.[20,29,33] Even though the same or similar resin cements were used in several studies, a direct comparison of each results is impossible due to differing study designs. Some resin cements like Secure, Smartcem and Zirconite was evaluated based on their radiopacity for the first time in this study and showed appropriate radiopacity. The radiopacity of the 11 remaining resin cements was reported in several previous studies[2,7,15,16,20−22,25,26,29,31−33] and the results were similar regardless of the minute changes in their composition with the passage of time in comparison with the aluminum step wedge, except M−bond. The radiopacity of M−bond was 7.2~7.3 mm Al in case of a 2 mm specimen in Tsuge et al.[7] contrary to 0.31 mm Al in the present study. Tsuge et al.[7] used different shades of M−Bond, such as 'Opaque Ivory' and 'Opaque Dentin' instead of the 'Clear' shade used in the present study. Interestingly, while the radiopacity of Rely X U200 (A2) and U−Cem (Universal) did not exceed 2 mm Al, contrary to their shade, Variolink N (Transparent), Nexus 3 (Clear), Multilink N (Transparent), and SmartCem2 (Translucent) showed a high radiopacity of more than 3 mm Al. This suggests that an understanding of the radiopacity prevents clinicians from presuming the radiographic appearance of resin cements based on their visual shade. According to ISO 4049[6], the radiopacity test is performed only with a representative ‘universal’ shade. However, resin cements with a transparent or clear shade used in esthetic locations may have a lower radiopacity value compared to the ‘universal’ shade. Although ISO 4049[6] suggests that it is not mandatory to include the ‘radiopaque’ resin-based luting cements in the manufacturer’ s instructions or the user information, prior knowledge of the radiopacity values would allow clinicians to choose the resin cements with the appropriate radiopacity and be more attentive while removing the excessive cements with lower radiopacity. The resin cements with lower radiopacity for esthetic use should not be used for other purposes. Therefore, the radiopacity of resin cements should be tested in all shades and included in the user information.

A suitable difference in the radiopacities of the resin cements is necessary to diagnose persistent or secondary caries, marginal gaps, and residual materials.[34-36] If the margin of the implant-prosthesis is located in the subgingival region, a suitable radiopacity of cements allows the detection of overhang, which can result in peri-implantitis.[8,39,37] An appropriate radiopacity is slightly greater than that of enamel and it can make an easy diagnosis of recurrent caries adjacent to the restoration and evaluate the homogeneity of the materials.[34-36] Rely X U200 and U-Cem were optimal among the tested materials in terms of the radiopacity, which showed similar or slightly higher radiopacity than that of the enamel. Titanium or other metals are used in implants and the radiopacities of the luting cements should be greater than of those materials.[29] In contrast, the materials with a similar or lower radiopacity than that of dentin can cause a difficulties in the diagnosis.[9] Variolink had the highest radiopacity among the tested materials, which might be unfavorable for the evaluation of homogeneity.

Radiopacity should be expressed as the equivalent thickness of aluminum compared with an aluminum step wedge and the purity of aluminum plays an important role for the accuracy according to the ISO recommendations (4049:2009).[6] Aluminum with 4% copper impurity by mass created a systematic error of 1.25% and obtained results comparable with high-purity wedges.[38] Therefore, the aluminum content of the wedge should be more than 98% by mass, and alloys with less than 0.1% copper or 1.0% iron should be used.[6] Some studies used human tooth alone[2,7,15,20,22,24,33] or in combination with bovine tooth[25] as a secondary internal standard along with the aluminum step wedge. They reported radiopacity values of the tooth structures to be 0.7 ~ 2.02 mm Al (mean, 1.36±0.41 mm Al) for dentin and 1.58~2.53 mm Al (mean, 1.97±0.39 mm Al) for enamel. Even though, the radiopacity of tooth structures showed a slight difference in the previous studies according to the experimental methods and aluminum step wedge used, the results supported the fact that aluminum step wedges were useful as a reference showing similar radiopacity of dentin of the same thickness.

Although several factors affect the radiopacities of dental materials, including the methodology used for evaluation[20] and the ratio of powder/liquid,[9] the most important factor seems to be the material composition.[39] In resin-based materials, the addition of fillers with a high atomic number provides suitable radiopacity and these fillers include aluminium, barium, strontium, zirconium, ytterbium, yttrium, and zinc.[9,15,40] The higher the atomic number of the element added, the higher the radiopacity of the material, since it increases the absorption capacity of X-rays. Radiopacity is also determined by the percentage of these elements.[9,15,40] It is difficult to know the accurate information on the detailed composition of dental composites, since this is rendered confidential by most manufacturers.[11]

V. Conclusion

PSP is precise under various exposure settings and the radiopacity of resin cements dose not differ depending on the various exposure settings using PSP. The radiopacity of the 14 tested contemporary resin cements, except M-bond, are greater than those of aluminum or dentin of the same thickness, complying with the requirements of the International Organization for Standardization.

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요약(국문초록)

영상판을 이용한 레진시멘트의 방사선불투과성 평가

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목적

합착용시멘트는 간접 수복물과 치아 또는 임플란트 지대주를 연결하는 역할을 하며 최근 레진시멘트의 사용이 크게 증가하고 있다. 정확한 진단을 위하여 영상에서 레진시멘트와 치아조직 사이의 적절한 방사선불투과성의 차이가 필요하며, 이를 위해서 레진시멘트는 충분한 방사선불투과성을 가져야한다. 레진시멘트는 기존의 시멘트에 비해 필러의 함량이 적어 방사선불투과성이 낮을 수 있으나 이에 대한 정보가 부족하다.

이 연구의 목적은 영상판을 이용하여 레진시멘트의 방사선불투과성을 평가할 때 촬영 조건이 미치는 영향을 알아보고 현재 사용되는 14가지 레진시멘트의 방사선불투과성을 최적의 촬영 조건에서 평가하는 것이다.

재료 및 방법

실험을 위해 14 종류의 레진시멘트를 그룹별로 6 개씩, 직경 7 mm, 두께 1 mm의 원반형 표본으로 제작하였으며, 치아는 치관 부위만 장축 방향으로 1 mm 두께로 준비하였다. 실험에 사용된 시멘트는 BisCem, Clearfil SA LUTING, Duolink, Maxcem Elite, M-bond, Multilink N, Nexus 3, Panavia F2.0, Rely X U200, Secure, SmartCem2, U-Cem, Variolink, Zirconite였다.

우선, 방사선불투과성 평가에 촬영 조건(관전압, kVp; 거리, cm; 노출 시간, 초)이 미치는 영향을 알아보고 가장 정확한 촬영 조건을 찾기 위하여, 선별된 4 종류의 레진시멘트(Duolink, Multilink N, Panavia F2.0 and U-Cem)를 알루미늄 스텝 웨지, 치아와 함께 9 가지의 조건으로 촬영하였다. 9가지 촬영 조건은 60 kVp -30 cm-0.100/0.125/0.160/0.200초, 70 kVp, 30 cm, 0.100/0.125/0.160초와 60 kVp-40 cm-0.160/0.200초였으며 관전류는 모든 조건에서 7 mA였다.

다음으로, 나머지 10 종류의 레진시멘트(BisCem, Clearfil SA LUTING, Maxcem Elite, M-bond, Nexus 3, Rely X U200, Secure, SmartCem2, Variolink and Zirconite)의 방사선불투과성을 평가하기 위하여 시편을 알루미늄 스텝 웨지, 치아와 함께 가장 정확도가 높은 '촬영 조건 8' (60 kVp-40 cm-0.16초-7 mA)을 이용해 영상판으로 촬영하였다.

레진시멘트, 알루미늄 스텝 웨지, 치아의 회색조 수치를 ImageJ 소프트웨어를 이용하여 측정하고, 회색조 수치를 흡수계수로 환산하였다. 엑셀을 이용하여 알루미늄 스텝 웨지의 두께와 흡수계수 간의 그래프와 수식을 구하고 이를 이용하여 각 레진시멘트의 알루미늄 등가치를 산출하였다. 결정계수(R^2)로 가장 정확한 노출 조건을 찾고, Kruskal-Wallis와 Tukey HSD test를 이용하여 노출 조건에 따른 레진시멘트의 값을 비교하였다.

결과

아홉 가지의 촬영 조건에 따른 알루미늄 스텝 웨지의 결정계수(R^2)는 0.9983에서 0.9997 사이로, 모두 높은 정확도를 나타내었고, ‘촬영 조건 8’에서 가장 높은 값을 보였다. 네 종류의 레진시멘트와 상아질, 법랑질의 알루미늄 등가치는, Panavia F2.0을 제외하고 촬영 조건에 따라 유의한 차이가 없었으며, 각각 Duolink가 1.02±0.13~1.31±0.23, Multilink N이 4.23±0.23~4.36±0.29, Panavia F2.0이 1.21±0.22~1.40±0.24, U-Cem이 1.90±0.46~2.05±0.25, 상아질이 0.70±0.21~1.00±0.21, 법랑질이 1.68±0.22~1.84±0.21의 값을 보였다.

나머지 10 종류의 레진시멘트의 방사선불투과성은 Variolink (5.71±0.09)가 가장 높았고, 그 다음으로 Nexus 3 (4.68±0.14), SmartCem2 (3.69±0.14), Maxcem Elite (2.95±0.12), Secure (2.91±0.11), Rely X U200 (1.96±0.19), Clearfil SA LUTING (1.71±0.10), Zirconite (1.60±0.08), BisCem (1.58±0.13), M-bond (0.31±0.45)의 순으로 나타났다.

결론

영상판은 다양한 촬영 조건에서 모두 높은 정확도를 보였으며, 레진시멘트의 알루미늄 등가치는 다양한 촬영 조건에 따라 차이가 없었다. 이번 연구에 사용된 14 종류의 레진시멘트는 M-bond를 제외하면 모두 국제표준화기구의 방사선불투과성에 대한 요구조건에 부합된다.

주요어 : 방사선불투과성; 레진시멘트; 영상판; 디지털방사선촬영술; 알루미늄 스텝웨지

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